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Trapping of Implanted He at Cu/Nb Interfaces Measured by Neutron Reflectometry

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Jon Baldwin, Jarek Majewski

LANSCE-LC



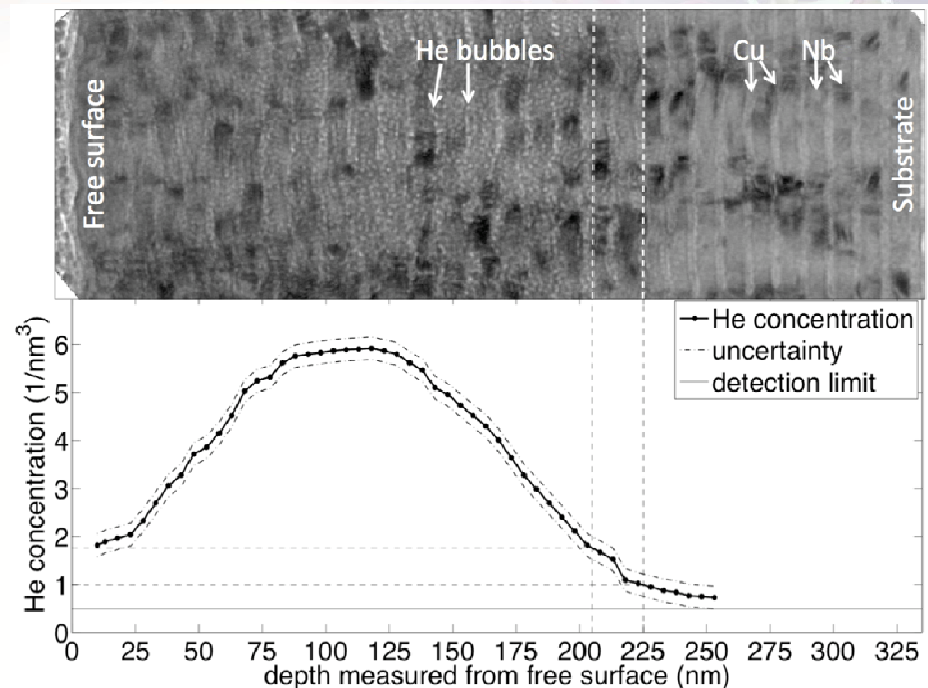
Motivation

In single crystalline metals, He is insoluble and precipitates into bubbles

In contrast, Cu-Nb multilayers show no evidence of bubble formation below a critical concentration

Questions

- How are the He atoms stored at the interface below the critical concentration?
- What is the C_{He} distribution?



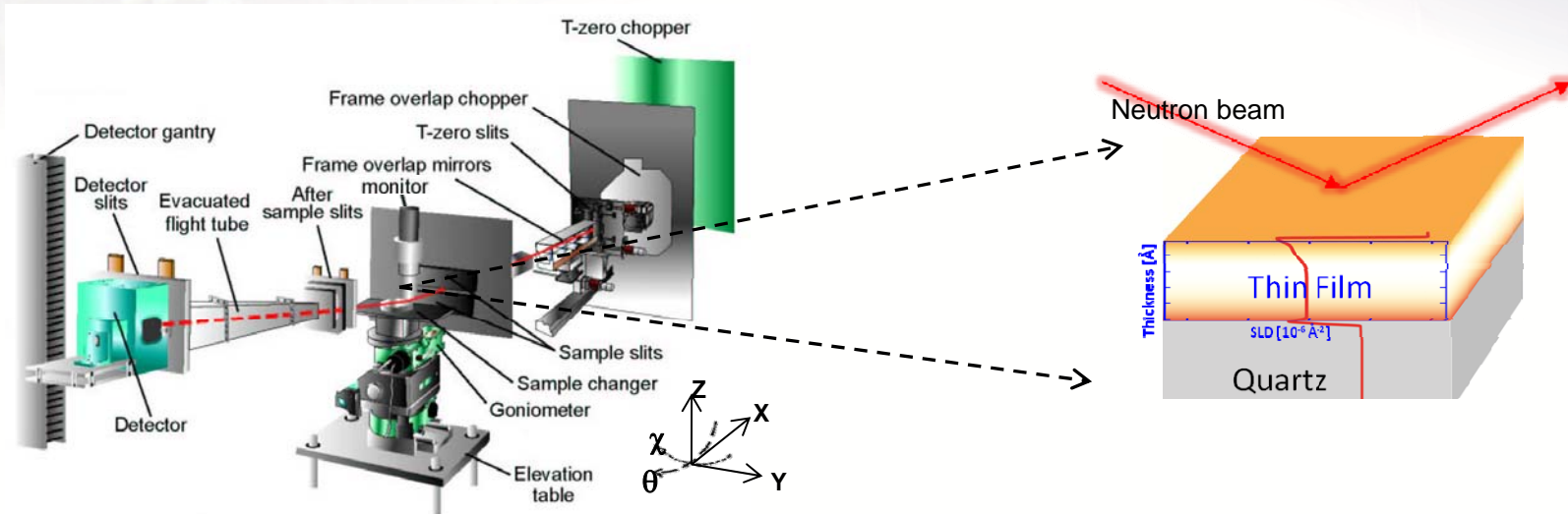
[1] M. J. Demkowicz *et al*, Appl. Phys. Lett. 97 (2010) 161903

In Cu-Nb multilayers, the critical interface He concentration to resolve bubbles under the TEM is 8.5 ± 2.5 atoms/nm² [1] (Multilayers implanted with 35 keV He³ with $10^{17}/\text{cm}^2$).

Why Neutron Reflectometry (NR)?

Advantages of NR:

- Element sensitive
- Angstrom level depth resolution
- Nondestructive in nature



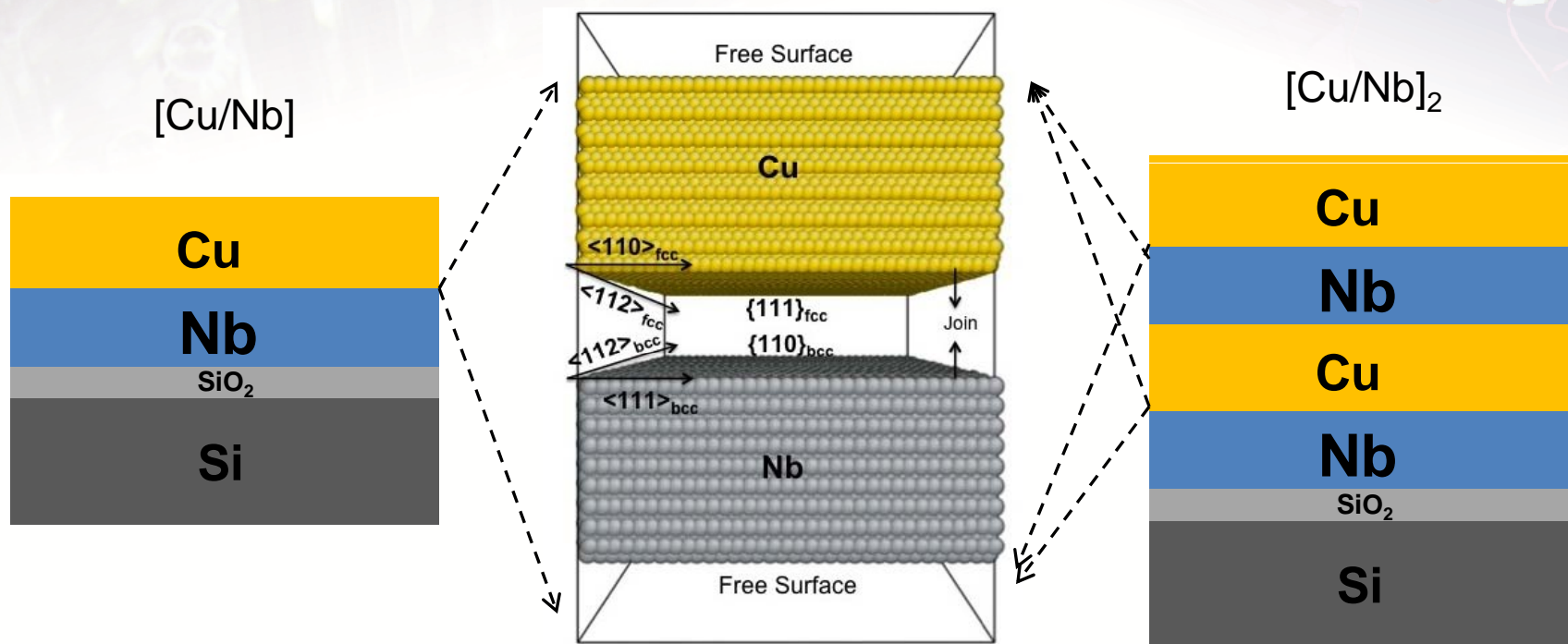
TEM: Cannot resolve He clusters smaller than 2 nm in diameter

Elastic Recoil Detection (ERD): NOT enough depth resolution

Nuclear Reaction Analysis (NRA): NOT enough depth resolution

Strategies and Sample Preparation

Cu/Nb bi-layers: Magnetron Sputtering
He Implantation: 20 KeV, 10^{17} ions/cm², $< 2 \mu\text{A/cm}^2$

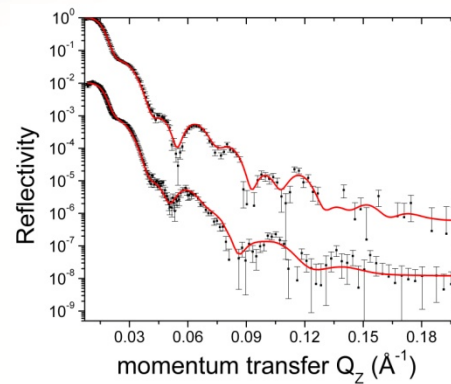
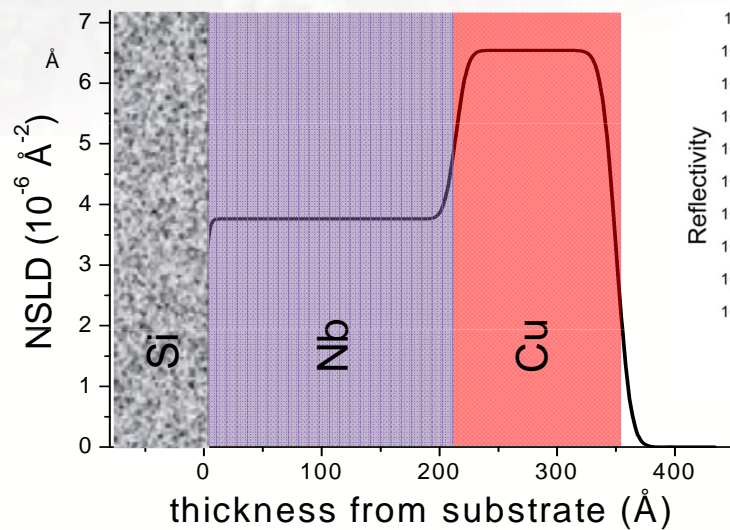


Construction of the Cu-Nb heterointerface.

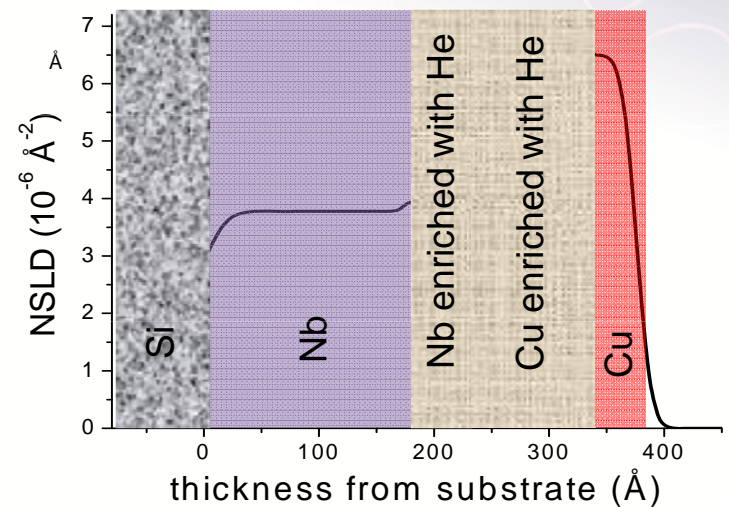
Kurdjumov-Sachs (KS) orientation relationship

Sample [Cu/Nb]

As-prepared



He-implanted



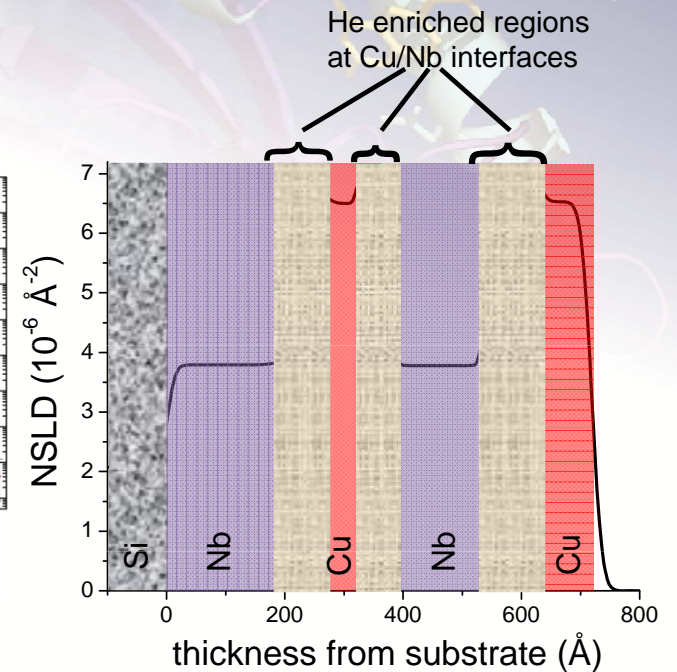
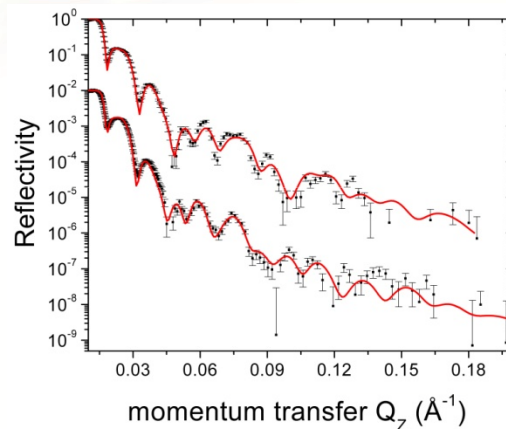
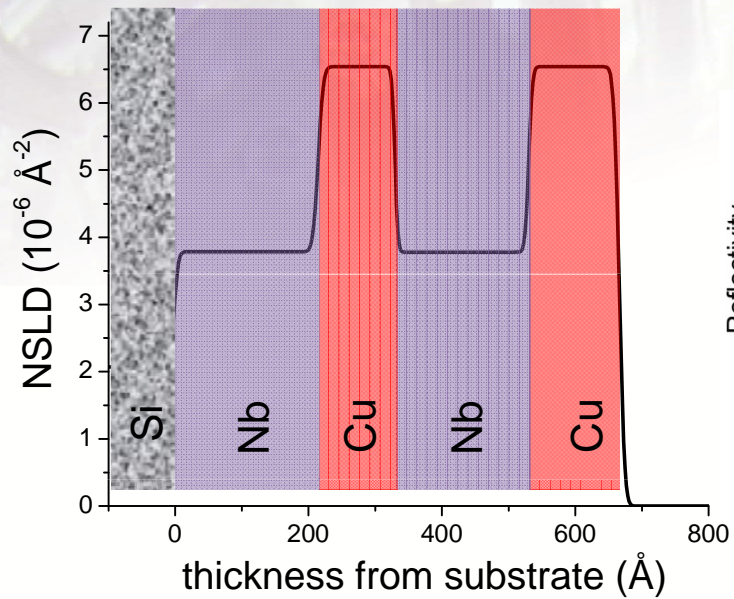
- He trapped at Cu/Nb interface
- Cu is preferred

Results on Sample [Cu/Nb]

	Layer	Thickness (Å)	SLD (10^{-6} Å^{-2})	Roughness (Å)	He (at. %)
As-prepared	Cu	136	6.54	14	
	Nb	211	3.76	11	
After Implantation	Cu	42	6.5	14.5	
	Cu + He	108	7.06	4	18
	Nb + He	53	3.95	15	12
	Nb	173	3.78	6	

- Significant broader interface
-- 160 Å vs. 11 Å
- Cu layer swelled 10%
- Nb layer swelled 7%

Sample [Cu/Nb]₂



- He trapped at Cu/Nb interface
- Cu is preferred

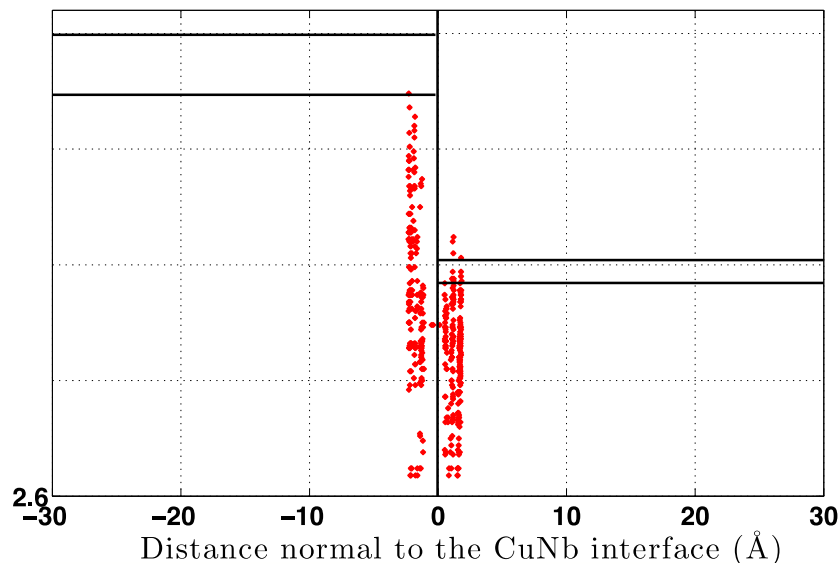
Results on Sample [Cu/Nb]₂

	Layer	Thickness (Å)	SLD (10 ⁻⁶ Å ⁻²)	Roughness (Å)	He (at. %)
As-prepared	Cu	136	6.54	9	
	Nb	201	3.78	6.4	
	Cu	115	6.54	5.3	
	Nb	216	3.78	8.8	
After Implantation	Cu	86	6.53	19.7	
	Cu + He	60	7.0	13	16
	Nb + He	45	4.2	10	20
	Nb	144	3.78	6	
	Nb + He	26	4.2	8.4	20
	Cu + He	40	6.86	19.8	12
	Cu	54	6.5	6	
	Cu + He	24	6.86	18.7	12
	Nb + He	60	3.95	6.4	10
	Nb	180	3.79	19.3	

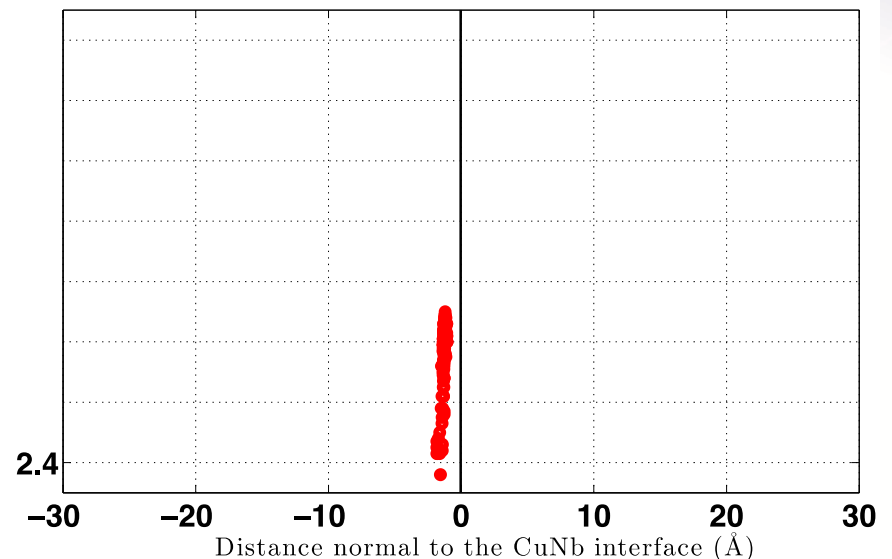
Similar behavior as [Cu/Nb] sample; Interfacial region swells ~ 10 times

Atomistic modeling

- Based on Cu-Nb-He EAM Potential
- The formation energy of He defects is **lower** at the Cu-Nb interface compared to fcc Cu and bcc Nb
- Cu/Nb interface is preferred



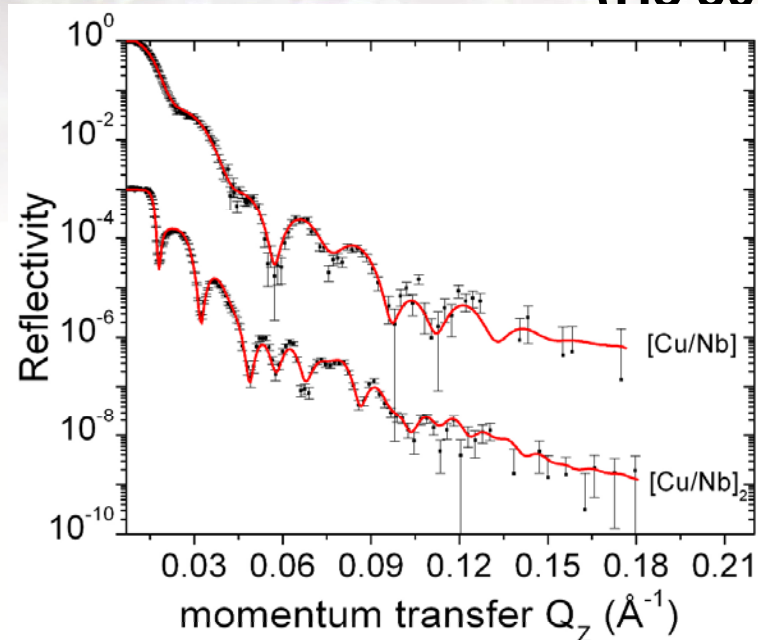
Variation of the He interstitial energy in the direction normal to the Cu-Nb interface



Variation of the He substitutional energy in the direction normal to the Cu-Nb interface

Control Sample

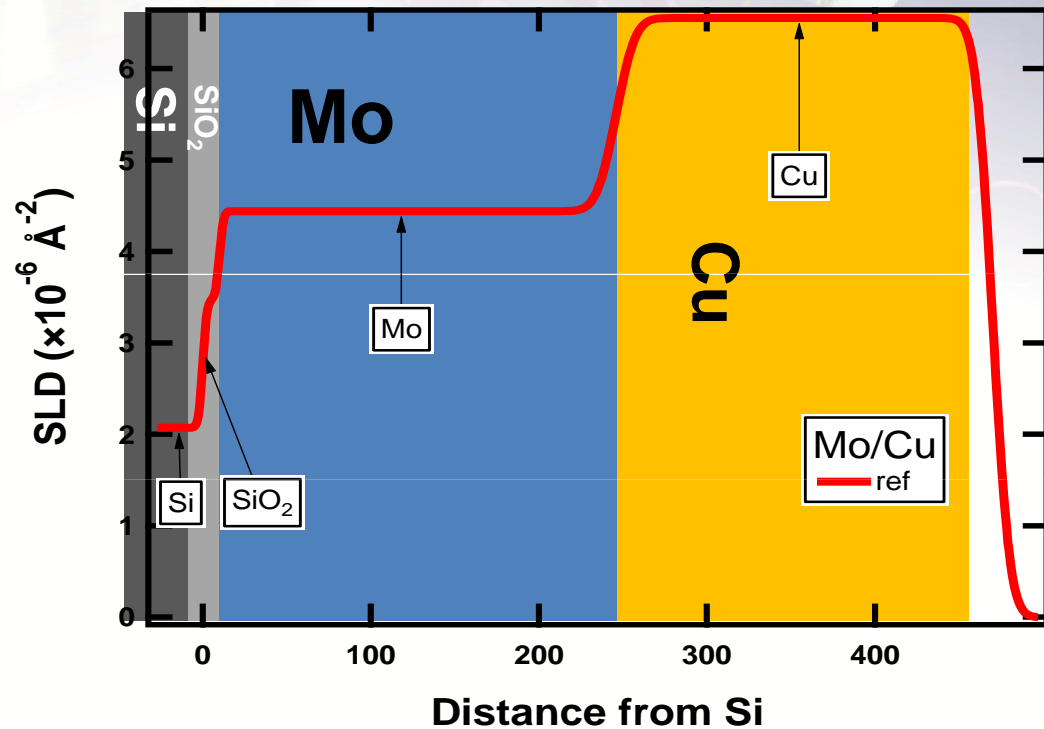
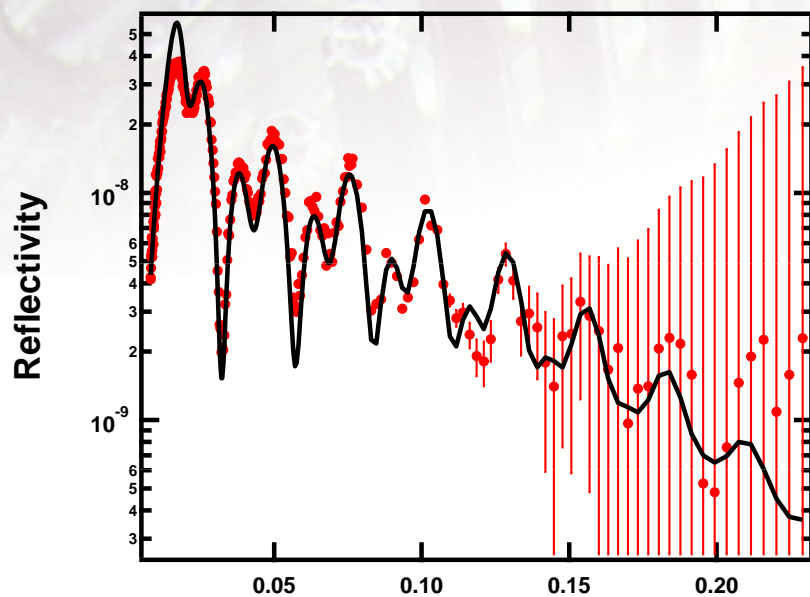
Cu/Nb bi-layers sputtered in He atmosphere (He 50% balanced with Ar)



	Layer	Thickness (\AA)	SLD (10^{-6}\AA^{-2})	Roughness (\AA)	He (at. %)
[Cu/Nb]	Cu	122	6.45	16.5	
	Nb	213	3.48	16	
[Cu/Nb] ₂	Cu	125	6.49	9	
	Nb	210	3.51	15	
	Cu	115	6.47	14	
	Nb	220	3.49	16	

- Homogeneous He distribution
- SLD_{Nb} : Reduced by 8%
- SLD_{Cu} : Reduced by 1%

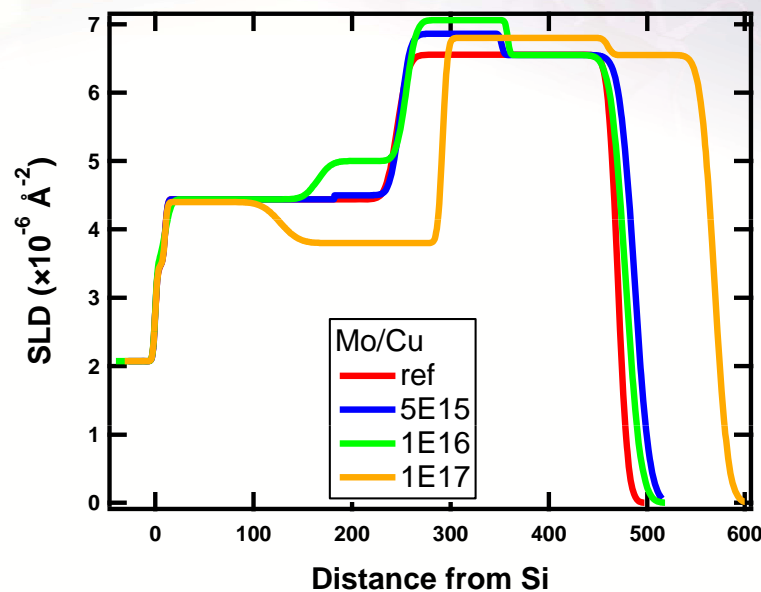
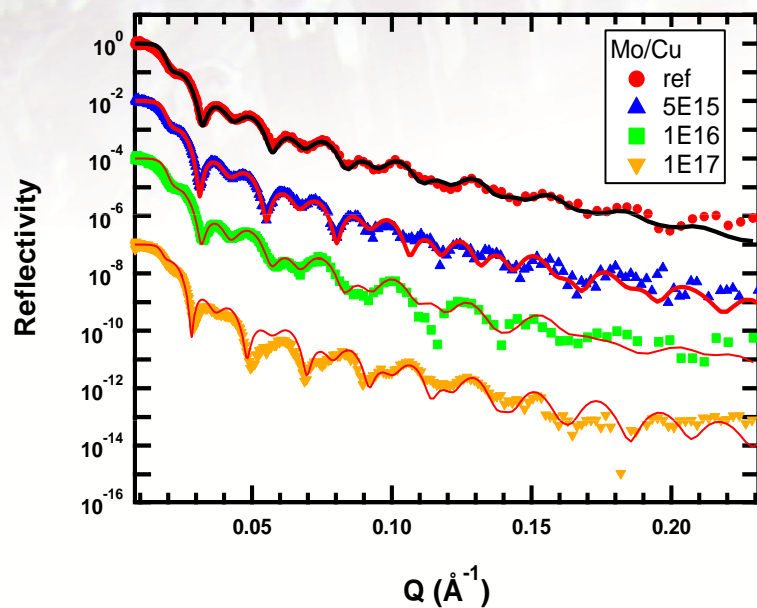
Cu/Mo Sample



Implanted with difference dose

Cu/Mo Sample

Dependence on Implantation Fluence



- Implantation Fluence has effect on the He trapping behavior
- Critical concentration can be determined

Conclusion

- He is trapped at Cu/Nb , Cu/Mo interfaces.
- He is trapped interstitially
- The interface swells ~ 10 times
- The layered structure retains despite the swell of interfaces.

Future work

- Cu/V system
- Annealing of the Implanted metal bi-layers
- ^3He vs. ^4He : Bigger cross section



Thanks